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FERTILIZERS ON CEREAL CROPS GROWN IN ROTATION.

BY CHAS. E. THORNE.

The Ohio Experiment Station is now conducting experiments in the use of fertilizers and manure on various farm crops at four different points in the state, namely: at the main Station at Wooster, Wayne county; at the Northeastern Test-farm at Strongsville, Cuyahoga county; at the Southwestern Test-farm at Germantown, Montgomery county, and at the Southeastern Test-farm at Carpenter, Meigs county.

The soil of the farm at Wooster is a somewhat sandy clay loam, lying upon one of the upper sandstones of the Waverly series, from which it is largely derived, though somewhat modified by glacial drift. That at Strongsville is a cold, heavy clay, lying upon an argillaceous shale of the same Waverly series, but also modified by the drift. These soils are both relatively deficient in lime, as are most of the soils on this formation.

The soil at Germantown is a clay loam, of the character generally found on the uplands of the Miami valley. It lies upon a deep bed of drift material, consisting chiefly of detritus from limestone rocks. That at Carpenter is quite similar in texture to the Germantown soil, but it has been derived from the breaking down of a sandstone belonging to the coal measures.

The Wooster and Germantown farms had been used chiefly in grain production for many years before the experiments were begun, with but little attention to fertilizing or manuring. That at Strongsville had lain in pasture for 20 to 25 years, and that at Carpenter had been the part of a large stock farm on which grain was grown for stock pastured on the remainder of the farm, and which had received considerable manure.

The experiments were begun at Wooster in 1894, at Strongsville in 1895, and at Germantown and Carpenter in 1904. We have, therefore, the results of 12 years' work at Wooster, of 11 years' at Strongsville, and of two years' at the other two test-farms.

Each of these farms was selected because it contained certain areas of land more than ordinarily uniform in character, and these areas have been devoted to this work. They have all been underdrained with tile drains, laid 36 feet apart, and every fertilized or manured plot lies between two untreated check plots, with which it is compared.

At Wooster and Strongsville the corn crop is followed by oats, wheat, clover and timothy, grown in a 5-year rotation. The corn is thus planted on timothy sod. At the southern test-farms corn is followed by wheat and clover, grown in a 3-year rotation, so that the corn will be grown on clover sod after the first rotation is completed. The two crops of corn herewith reported have been grown on stubble land or timothy sod. The rotations are all so arranged that each crop is grown every season.

On one plot in these experiments phosphorus, carried in acid phosphate, is the only fertilizing material used, being applied at the rates of 80 pounds per acre at Wooster and Strongsville and of 120 pounds at the southern test-farms. In the 5-year rotation the oats crop receives 80 pounds of acid phosphate and the wheat, 160 pounds, in addition to that given the corn, and in the 3-year rotation the wheat receives 120 pounds, thus making a total of 320 pounds given every 5 years in the longer rotation and of 240 pounds every 3 years in the shorter one, the clover and timothy crops receiving no direct fertilizing.

On another plot potassium, carried in the chloride (muriate of potash) is added to the acid phosphate, at the rate of 80 pounds each on corn and oats and 100 pounds on wheat, a total of 260 pounds in the longer rotation, and of 20 pounds each on corn and wheat, or a total of 40 pounds per rotation, in the shorter one.

On a third plot nitrogen, as carried in sodium nitrate, (nitrate of soda) is substituted for the potassium, being used at the rate of 160 pounds on each of the 3 cereal crops, or 480 pounds per rotation, in the longer rotation, and at the rate of 80 pounds each for corn and wheat, in the shorter one.

On a fourth plot the three fertilizing materials are combined, being used in every case at the rates above given. The fertilizers are applied in all cases with the ordinary grain fertilizer drill, and are distributed over the entire surface of the ground, never in the hill or drill. The fertilizing is done immediately before planting the grain, except in the case of wheat. This crop receives its full allowance of phosphorus and potassium in the fall, together with about one fourth its nitrogen ration, given in dried blood or tankage, the remainder of the nitrogen being given in April in nitrate of soda.

TABLE I—RESULTS FOR THE CORN CROP.

Fertilizing elements	Station	Fertilizers per acre				Increase or decrease (—) of corn per acre					
		Acid phosphate	Potassium chloride	Sodium nitrate	Cost	First period: Grain	First period: Stover	First period: Value	Second period: Grain	Second period: Stover	Second period: Value
		Lbs.	Lbs.	Lbs.	$	Bus	Lbs.	$	Bus	Lbs.	$
Phosphorus alone	Wooster	80	..	..	0.60	3.96	3	1 59	9.66	303	4 32
	Strongsville	80	..	..	0.60	3.98	17	1 63	13.94	287	6.01
	Germantown	120	..	..	0.90	7 88	227	3 49	....	..	....
	Carpenter	120	..		0.90	1.19	—45	0 41	..	..	...
Phosphorus and potassium	Wooster	80	80	..	2.60	7 21	285	3.31	15 80	692	7 36
	Strongsville	80	80	..	2.60	4 54	—103	1.66	11 23	359	5 03
	Germantown	120	20	..	1.40	8.71	683	4.51	....	..	....
	Carpenter	120	20	..	1.40	2.73	325	1 57	....	..	....
Phosphorus and nitrogen	Wooster	80	..	160	4 60	9 65	217	4.18	16.73	475	7 40
	Strongsville	80	..	160	4 60	6 62	44	2.71	13.00	345	5.72
	Germantown	120	..	80	2 90	6 31	253	2.90	....	..	....
	Carpenter	120	..	80	2 90	2.93	128	1 36	....	..	....
Phosphorus, potassium and nitrogen	Wooster	80	80	160	6.60	10 72	323	4 77	20 08	793	9 22
	Strongsville	80	80	160	6.60	9 43	240	4 13	13 42	543	6 18
	Germantown	120	20	80	3 40	7.97	315	3.66	....	..	....
	Carpenter	120	20	80	3.40	4.69	265	2.27	....	..	....

FERTILIZERS ON CORN.

In Table I are given the results on the corn crop to date. This table shows the quantity and cost of the fertilizing materials applied directly to the corn crop at each station and the quantity and value of the increase from the fertilizers, estimating corn at 40 cents per bushel and stover (fodder) at $3.00 per ton. For the Wooster and Strongsville stations this increase is computed for two periods: the first period including the 5 years of the first rotation, and the second period covering the years since this first period. During this later period the corn has been grown on land that has had five years' treatment under the plan of the experiment, this second period including 7 corn crops at Wooster and 6 at Strongsville. It will be observed that the increase from the fertilizers has in every case been very much greater during the second period than during the first.

The upper section of Table I shows that the increase from phosphorus alone, applied in acid phosphate at the rate of 80 pounds of this carrier per acre, has produced sufficient increase of corn to repay the cost of the fertilizer from two to three times over, except at Carpenter.

When potassium has been added to the phosphorus the increase, as shown by the second section of the table, has repaid the cost of the fertilizer in every case except during the first period at Strongsville. At Wooster the increase from the combination of phosphorus and potassium has been proportionally greater than that from phosphorus alone during both periods, but at Strongsville potassium seems to have added nothing to the effectiveness of the fertilizer for corn in either period, the increase from phosphorus and potassium being smaller than that from phosphorus alone.

When nitrogen has been substituted for potassium the increase, as shown in the third section of the table, has not been sufficient to cover the greatly increased cost of the fertilizer during the first period, except at Germantown, where the quantity of nitrogen added has been only half as great as that at Wooster and Strongsville. During the second period the cost of the fertilizer has been recovered with profit, but it appears again that the increase at Strongsville is no greater than that from phosphorus alone.

When the three fertilizing elements have been combined the increase, as shown in the last section of the table, has only covered the cost of the fertilizer at Germantown for the first period, and only at Wooster for the second; the increase at Strongsville being again practically no greater than that from phosphorus alone.

Taking the results as a whole and considering the corn crop only, it appears that acid phosphate has been used with profit in every case except at Carpenter, and it is quite possible that the apparent failure to produce a profitable increase at Carpenter has been due to the inequalities in the plots, and not to lack of need for phosphorus, as the one wheat crop harvested at this station has shown a large increase on the plot receiving phosphorus alone.

The corn, grown on old timothy sods or stubble land at Wooster and Germantown, has also given at once a profitable increase from the combination of phosphorus and potassium; but the addition of nitrogen to this combination has not produced a profitable increase during the first rotation in any case. During the second period of the test the addition of nitrogen has considerably increased the total yield at Wooster, but the greater cost of the fertilizer has left a smaller net return than where the nitrogen was omitted. Neither nitrogen nor potash has increased the yield of corn on the old pasture land at Strongsville during either period of the test.

FERTILIZERS ON OATS.

As has been stated above, the corn crop is followed by oats at Wooster and Strongsville, the oats being separately fertilized. The results for this crop are shown in Table II, oats being valued at 30 cents per bushel and straw at $2.00 per ton.

TABLE II—RESULTS ON THE OATS CROP.

Fertilizing elements	Station	Fertilizers per acre				Increase per acre					
						First period			Second period		
		Acid phosphate	Potassium chloride	Sodium nitrate	Cost	Grain	Stover	Value	Grain	Stover	Value
		Lbs.	Lbs.	Lbs.	$	Bus.	Lbs.	$	Bus.	Lbs.	$
Phosphorus alone	Wooster	80	..	..	0 60	5 34	83	1.68	10.44	412	3.54
	Strongsville	80	..	..	0 60	10.07	365	3 38	11 04	409	3.72
Phosphorus and potassium	Wooster	80	80	..	2.60	6 87	277	2.34	14.70	623	5.03
	Strongsville	80	80	..	2.60	10.99	395	3.69	10.44	497	3 63
Phosphorus and nitrogen	Wooster	80	..	160	4 60	8.26	299	2 78	19.62	789	6.67
	Strongsville	80	..	160	4.60	13.43	458	4.49	16.37	597	5.51
Phosphorus, potass. and nitrogen	Wooster	80	80	160	6.60	12 92	609	4.48	22 86	1,015	7.87
	Strongsville	80	80	160	6.60	12.72	545	4.36	16.86	684	5.74

This table shows that the oats crop, like the corn, has paid for the phosphorus, when used alone, with an ample margin. It has also paid for the addition of potassium, except during the first period at Wooster, but the net gain from the combination of phosphorus and potassium, after deducting the cost of the fertilizers, has been smaller than that from phosphorus alone, and this is also true when nitrogen has been substituted for potassium, although this substitution has increased the total yield in a marked degree. The largest total yield has come from the complete fertilizer, but the additional cost of the fertilizer has lowered the net gain at Wooster and wiped it out at Strongsville.

FERTILIZERS ON WHEAT.

In the long rotation at Wooster and Strongsville the wheat crop has received 160 pounds of acid phosphate per acre, or as much as the combined application to the two preceding crops in the rotation, and 100 pounds of potassium chloride, instead of 80 pounds. It has received nitrogen equivalent to that carried in 160 pounds of sodium nitrate. About one fourth of the nitrogen ration has been given in dried blood in the fall, together with the full ration of phosphorus and potassium, the remainder of the nitrogen being given in nitrate of soda, sown broadcast over the wheat in April; this method being adopted to prevent the waste of nitrogen which would probably occur were the whole ration given in nitrate of soda in the fall, as this is an easily soluble salt, and much of it would probably be leached out of the soil by the winter and early spring rains. When applied after the growth has started in the spring it is immediately taken up by the plant, producing a marked acceleration of growth. In the shorter rotations the wheat receives the same quantities of fertilizing materials as the corn, but here also the nitrogen is applied to wheat as in the longer ones.

TABLE III—RESULTS ON THE WHEAT CROP.

Fertilizing elements	Station	Fertilizers per acre				Increase per acre					
						First period			Second period		
		Acid phosphate	Potassium chloride	Sodium nitrate	Cost	Grain	Straw	Total	Grain	Straw	Total
		Lbs.	Lbs.	Lb.	$	Bus	Lbs	$	Bus.	Lbs	$
Phosphorus alone	Wooster	160		..	1.20	3 14	426	2.94	10.25	884	9 08
	Strongsville	160	..	..	1 20	5 51	696	5 10	9.45	721	8 28
	Germantown	120		..	0.90	4 82	321	4.18	....	.	..
	Carpenter	120			0 90	7 29	165	6 00	.	..	.
Phosphorus and potassium	Wooster	160	100	..	3.70	5.22	465	4.64	11 16	896	9 82
	Strongsville	160	100	..	3 70	6 23	578	5 56	9 59	686	8 36
	Germantown	120	20	..	1 40	5 76	454	5 06	....	..	...
	Carpenter	120	20	..	1 40	10 50	567	8 97	....	.	.
Phosphorus and nitrogen	Wooster	160	..	160	5 20	6 81	893	6 34	16 07	1,502	14 36
	Strongsville	160	..	160	5 20	8.11	845	7.33	11.58	915	10 18
	Germantown	120	..	80	2.90	6.91	435	5 96	....	..	...
	Carpenter	120	..	80	2 90	12 86	952	11.24	....	..	...
Phosphorus potassium and nitrogen	Wooster	160	100	160	7.70	10 73	1,331	9 91	18.91	1,931	17 06
	Strongsville	160	100	160	7 70	8 92	826	7 96	10 58	1,056	9 52
	Germantown	120	20	80	3 40	9 69	830	8.58	....	..	...
	Carpenter	120	20	80	3 40	12 65	924	11.04	....	..	....

Table III shows the results obtained in the wheat crop under this plan of fertilizing. This table gives the average increase in 7 crops of wheat grown at Wooster and in 5 grown at Strongsville, and that in one crop each at Germantown and Carpenter. This table shows that the wheat crop, valuing wheat at 80 cents per bushel and straw at $2.00 per ton, has paid for every fertilizing application and at every station, with a large margin in every case except where the complete fertilizer is used at Strongsville. Here, during the first period, the margin was small. At Wooster, however, the complete fertilizer has produced not only a larger total increase but a larger net gain as well, during both periods of the test, than any partial application. It is evident, moreover, that at both Wooster and Strongsville nitrogen has been the most effective element in increasing the yield of wheat, next to phosphorus, but at Strongsville the additional increase from nitrogen has thus far been so small that its use can hardly be justified. With wheat, as with corn and oats, it appears that phosphorus is the only fertilizing element that has been used with profit at this test-farm.

At both the southern test-farms the wheat apparently shows a marked increase from the addition of either potassium or nitrogen to the phosphorus, but the work has not gone far enough at these stations to justify definite conclusions.

RESIDUAL EFFECT OF FERTILIZERS ON GRASS CROPS AND TOTAL EFFECT ON ENTIRE ROTATION.

As already explained, the fertilizers are applied only to the grain crops; the clover and timothy receive no direct fertilizing, but simply get what is left from the treatment given to the previous crops. In Table IV is shown the increase found in these crops (that for the two years of clover and timothy in the longer rotation being added together) and also the total amount of fertilizers applied during the rotation and their cost; the total value of the increase, rating corn at 40 cents per bushel, oats at 30 cents, wheat at 80 cents, stover at $3.00 per ton, straw at $2.00 and hay at $8.00; and the net value, as found after deducting the cost of the fertilizers from the total value.

TABLE IV—RESULTS FOR THE ENTIRE ROTATION.

Fertilizing elements	Station	Total fertilizers per acre				First period			Second period		
		Acid phos-ph'te	Potassium chloride	Sodium nitrate	Cost	Increase in hay crops	Total value of increase	Net gain	Increase in hay crops	Total value of increase	Net gain
		Lbs.	Lbs.	Lbs.	$	Lbs.	$	$	Lbs.	$	$
Phosphorus alone	Wooster	320	..	..	2.40	573	8 50	6.10	352	18.35	15.95
	Strongsville	320	..	..	2.40	1,090	14.47	12.07	1,485	23.95	21.55
	Germantown	240	..	..	1.80	330	8.99	7.19	....	....	....
Phosphorus and potassium	Wooster	320	260	..	8.90	1,027	14.40	5.50	967	26.08	17.18
	Strongsville	320	260	..	8.90	1,307	16 14	7.24	826	20.32	11.42
	Germantown	240	40	..	2.80	680	12.29	9.49	....	....	....
Phosphorus and nitrogen	Wooster	320	..	480	14.40	1,447	19.09	4.69	1,702	35.24	20.84
	Strongsville	320	..	480	14.40	1,017	18.60	4.20	1,082	25.74	11.34
	Germantown	240	..	160	5.80	967	12.73	6.93	....	....	....
Phosphorus potass., and nitrogen	Wooster	320	260	480	20.90	1,808	26.39	5.49	20.81	42.47	21.57
	Strongsville	320	260	480	20 90	1,571	23.35	2.45	8.07	24.67	3.77
	Germantown	240	40	160	6 80	1,303	17.45	10.65	....	...	....

This table shows that with the hay crops, as with wheat, there has been at Wooster a much larger increase from the complete fertilizer than from any partial fertilizer, and that the increase has been much greater on the plots which had received sodium nitrate. It also shows that the hay crops, unlike the grain crops, have given a smaller increase during the second period than during the first. Other experiments have shown that this falling off in yield of hay is due to exhaustion of the soil stores of lime, causing an almost complete failure of the clover crop. It appears that lack of lime is also responsible for part of the irregularity in hay yields at Strongsville.

Taking the total results of the experiment, we find that the application of 320 pounds of acid phosphate, distributed over the three grain crops, has produced an average total increase in the 5 crops of the longer rotation at Wooster to the value of $8.50 during the first 5 years and $18.35 during the last 7 years. At Strongsville the average value of the increase has been $14.47 for the first period, and $23.95 for the second. Deducting the cost of the fertilizer, the net gain has been $6.10 and $15.95 for the two periods at Wooster, and $12.07 and $21.55 at Strongsville.

The addition of 260 pounds of potassium chloride, costing $6.50, to the above dressing of acid phosphate, thus increasing the total cost of the fertilizer to $8.90, has reduced the net gain at Wooster to $5.59 for the first period, but increased it to $17.18 for the second. At Strongsville this addition has reduced the net gain to $7.24 for the first period and $11.42 for the second. The substitution of 480 pounds of sodium nitrate, costing $12.00, for the potassium chloride, thus increasing the cost of the fertilizer to $14.40 for the rotation, has reduced the net gain at Wooster to $4.69 for the first period, but has increased it to $20.84 for the second. At Strongsville this substitution has increased the total yield but has reduced the net gain to $4.20 and $11.34, for the two periods.

When both potassium chloride, and sodium nitrate have been added to the acid phosphate, thus increasing the cost of the fertilizer to $20.90 for the rotation, the net gain at Wooster has been $5.39 for the first period and $21.57 for the second, and at Strongsville, $2.45 and $3.77 for the two periods respectively.

At Germantown the highest net gains, thus far, are found on the plots receiving only phosphorus and potassium, although the complete fertilizer has given a little greater total gain.

GENERAL RESULTS.

It thus appears that on these soils an active carrier of phosphorus, such as acid phosphate (and other experiments indicate that steamed bone meal might have produced even better results) has been profitably used on all crops and on all the soils under experiment, except possibly at Carpenter.

It also appears that while the addition of carriers of phosphorus and potassium has seemed of doubtful utility for corn and oats in the earlier years of the work, yet when the results for the entire rotation are summed up, after time has been given for the fertilizers to perform their full service, we find that on the thin, hard run soil at Wooster, the fertilizer carrying these elements as well as phosphorus has produced not only the greatest total increase but also the greatest net gain.

On the Strongsville land, however, where phosphorus has produced a larger increase than at Wooster, it has not been profitable to add potassium or nitrogen, at least not in the large quantities employed at Wooster. It will be remembered that the Strongsville land had lain in pasture for many years before the experiment began, during which period it was being gradually depleted of its phosphorus to build up the bony framework of the animals grown upon it, while the nitrogen and potassium consumed in the pasture grasses were nearly all returned to the soil.

Phosphorus alone, however, has not brought up the yield of this land to a satisfactory point, and there is reason to suspect that it has been depleted of lime as well as of phosphorus, and that this also must be returned in quantity not only sufficient to restore that taken away, but also to alter the physical texture of the soil.

At Germantown the need of potassium as well as of phosphorus is indicated, not only by the experiments here reported, but also by those on tobacco, reported in Bulletin 172 of this Station.

Phosphorus is evidently, therefore, the fertilizing element first needed on the soils under experiment, and probably on most Ohio soils; but the maximum production has not been reached in these experiments until the phosphorus was reenforced with nitrogen at least, if not with both nitrogen and potassium. But when these two elements have been purchased they have so greatly increased the cost of the fertilizer that in most cases the net gain has been smaller than when they have been omitted, The question is naturally raised, therefore: Is there not some cheaper source of these elements than is found in commercial fertilizers?

FARM MANURE AS A SOURCE OF NITROGEN AND POTASSIUM.

As the cereal crops approach maturity there is a partial separation of their chemical constituents; the nitrogen and phosphorus accumulating in the grain, until about three fourths of that held by the entire plant is found there, while the straw or stover contains the major portion of the potassium. Hence, when the grain is sold, it carries away from the farm an undue proportion of phosphorus and nitrogen, and there will in time result a deficiency of these elements in the soil, as compared with potassium, unless the supply of this also is reduced by the selling of hay and straw, or of leafy plants, such as tobacco.

If mixed farming be practiced, including the growing and fattening of live stock, most of the potassium will be retained on the farm; but there will still be a heavy loss of phosphorus in that carried away in the bones of animals grown on the farm.

In early Ohio practice wheat was grown and sold off the farm, while corn and hay were fed to live stock. Of recent years, however, less live stock has been kept and more grain sold, together with much hay and straw. The result is that there are few soils in Ohio in which the need of phosphorus is not becoming manifest, while some are also beginning to show deficiency in potassium. The nitrogen supply also is generally more or less deficient.

A ton of average mixed farm manure, as taken from open barnyards, may be expected to contain 9 pounds of nitrogen, 10 of potassium, and 3 to 4 of phosphorus. Under average conditions Ohio soils would seem to require more phosphorus, in proportion to nitrogen and potassium, than that contained in manure, and in 1897 an experiment was begun at this Station in the reenforcement of manure with phosphorus, the materials used for this purpose being the finely ground phosphate rock, known as "floats", from which acid phosphate is made, and acid phosphate itself.

In this experiment corn, wheat and clover are grown in rotation, the corn crop being manured at the rate of 8 tons per acre and the wheat and clover following without any further manuring or fertilizing. Duplicate plots are treated with manure originally of the same character, but in one case the manure has lain in an open barnyard through the winter, while in the other it has been trampled under foot during accumulation and kept under cover until a short time before application, at which time both kinds of manure are mixed with the phosphatic materials, using 40 pounds of each to the ton of manure, after which the manure is spread on the clover sod and plowed under for corn. The land under experiment is divided into plots of uniform size, every third plot being left continuously without manure or fertilizer of any kind, and in computing the increase due to the manures the yield of each manured plot is compared with that of the two unmanured plots between which it lies, not with the average of all the unmanured plots.

TABLE V—RESULTS ON CORN AND WHEAT.

MANURE AND TREATMENT	Total yield		Total increase			Gain for treatm't
	Grain Bus.	Stover or straw Lbs.	Grain Bus.	Stover or straw Lbs.	Value $	$
CORN						
Average unmanured yield	37.36	2,198	....	....	....	....
Yard manure, untreated	51 43	2,936	14.70	744	7.00	....
" " with gypsum	57.35	3,340	19.02	1,014	9.13	2.13
" " " floats	58 20	3,310	19.85	1.085	9.57	2.57
" " " acid phosphate	59.05	3,234	24.40	1,142.	11 47	4 47
Stall manure, untreated	57.13	3,362	19.38	1,076	9.37	...
" " with gypsum	59.40	3,556	22.37	1,344	10.96	1 59
" " " floats	61 97	3.614	25 38	1,448	12.32	2.95
" " " acid phosphate	62.28	3,522	27.81	1,446	13.29	3 92
WHEAT						
Average unmanured yield	8.90	1,022	....	....	....	....
Yard manure, untreated	16.27	1,805	8.36	897	7 58	....
" " with gypsum	22.09	2.445	11.96	1.211	10 78	3 20
" " " floats	22 51	2,425	13 00	1.272	11.67	4 09
" " " acid phosphate	22.47	2,329	14.11	1,374	12 66	5.08
Stall manure, untreated	17 92	1.962	9.97	1.024	9 00	....
" " with gypsum	22 17	2,429	13.17	1.374	11 91	2 91
" " " floats	24 77	2,627.	15 71	1,572	14 14	5.14
" " " acid phosphate	24 20	2,588	16 09	1,634	14 51	5.51

Table V shows the 9-year average yield of corn and wheat obtained in this test, both without manures and with the variously treated manures, the manures for one pair of plots being treated with gypsum (land plaster) because of the well known property of that material of arresting escaping ammonia.

The table also shows the increase from the manures, computed as above stated, and the additional gain due to the treatment of the manures with the various materials, a gain which in the corn crop alone has more than offset the cost of the treatment, which has been $1.28 for the gypsum and floats, and $2.40 for the acid phosphate.

TABLE VI—RESULTS ON CLOVER AND TOTAL OUTCOME.

MANURE AND TREATMENT	Yield and increase of clover			Gain for treatment	Cost of treatment	Net value of total increase	Net gain for treatment
	Total yield	Total increase	Value of increase				
	Lbs.	Lbs.	$	$	$	$	$
Average unmanured yield....	1,963	....	....	....	....	....	....
Yard manure, untreated.....	2,531	686	2.74	....	....	17.32	....
" " with gypsum.	3,280	1,022	4 09	1.35	1.28	22.72	5.40
" " " floats....	3,866	1,727	6.91	4.17	1.28	26.87	9 55
" " " acid phos	3.533	1,826	7 30	4.56	2 40	29 03	11 71
Stall manure, untreated......	3,270	1,309	5.24	....	... .	23.61	....
" " with gypsum..	3,325	1,331	5.32	.08	1.28	26 91	3 30
" " " floats.....	4,458	2,504	10.02	4.78	1.28	35.20	11.59
" " " acid phos..	4.291	2,603	10.41	5 17	2.40	35.81	12 20

In Table VI is given the yield and increase of the hay crop, with the value of the increase, rating hay at $8.00 per ton. This table also shows the cost of treatment, the net value of the average total increase from the three crops of the rotation, after deducting the cost of treatment, and the net gain due to the treatment.

Tables V and VI show clearly that the phosphatic materials have been much more effective than the gypsum, the net gain for treatment due to these materials averaging more than double that due to the gypsum. They show, also, that yields of corn and wheat which have been brought up by systematic manuring to a 9-year average of more than 57 and nearly 18 bushels per acre, respectively, have been increased to 62 and 24 bushels, respectively, by reenforcing the manure with carriers of phosphorus.

These tables also show that by adding 320 pounds of acid phosphate to 8 tons of stable manure and applying this to land on which corn, wheat and clover are grown in rotation, we have obtained a 9-year average increase from the three crops of the rotation to the value of $38.21, or $12.74 per annum, as against a 7-year average increase from corn, oats and wheat, clover and timothy, grown in a 5-year rotation, worth $42.47 per rotation, or $8.49 annually, from the same quantity of acid phosphate used in connection with 480 pounds of sodium nitrate, costing $12.00, and 260 pounds of potassium chloride, costing $6.50, or a total of $18.50. In other words, the 8 tons of manure has produced an annual increase greater by 50 percent than chemicals costing $18.00. The 8 tons of manure, as used in this test, contained approximately the same quantity of nitrogen carried in 480 pounds of nitrate of soda, with somewhat less potassium than would be found in 260 pounds of potassium chloride. It is true that the manure has contained a considerable amount of phosphorus besides that added in the floats or acid phosphate, but after making full allowance on this point it would seem that the nitrogen and potassium of the manure, when that has been reenforced with phosphorus, have been fully as effective, pound for pound, as the same elements carried in sodium nitrate and potassium chloride; but no more effective carriers than these are in use as fertilizers.

The experiments above described have been made on soils of less than average fertility. They show that, after land has been brought up to an average yield of 57 bushels of corn and nearly 18 of wheat per acre with stable manure, a further and profitable increase may be made by the addition of a carrier of phosphorus. In another experiment potatoes, wheat and clover have been grown in a 3-year rotation on land at the main station, part of which had been cleared from the forest for the purposes of this experiment, while the remainder was land that had been kept in good condition by manuring and crop rotation. For the last six years two of the unfertilized plots in this test have averaged 33½ bushels of wheat per acre, while a plot between, receiving acid phosphate only, has averaged 40½ bushels, and the one receiving the complete fertilizer has averaged but 41 bushels, thus showing that phosphates may sometimes be used with profit on very fertile soils. It is probable that the yield of corn may be similarly increased, especially on lands which have been in cultivation for a considerable time, even though they are still producing more than average crops.

SUMMARY AND CONCLUSIONS.

In these experiments corn and oats have profitably responded to applications of phosphorus in moderate quantities, and it is probable that the use of acid phosphate or steamed bone meal on these crops, at the rate of 80 to 100 pounds per acre, will be found profitable on most of the soils of the state.

Corn and oats have sometimes, but not always, returned a profitable increase when potassium has been added to the phosphorus in the fertilizer. The use of potassium seems to be especially indicated in regions where hay and straw, as well as grain, have been sold off the land for a considerable period, or where tobacco, cabbage or other crops in which the entire plant is taken off the farm, have been extensively grown.

The complete fertilizer, containing nitrogen and potassium, as well as phosphorus, has nearly always produced a larger total increase of corn and oats than any partial fertilizer; but when the nitrogen and potassium have been purchased in commercial fertilizers their cost has usually been greater than the additional gain, over that produced by phosphorus alone, has been worth.

The complete fertilizer has invariably produced a larger increase in the wheat crop than that given by any partial fertilizer, and on the hard-run land at the main station, which has been exhaustively cropped with cereals for 60 to 75 years, the additional increase in the wheat and hay crops resulting from the use of the complete fertilizer has more than offset its largely increased cost, leaving a larger net gain than that obtained from any partial fertilizer; but on land that had been resting in pasture for many years or on land in a high state of fertility, the increase from the complete fertilizer has not yet been sufficient to justify its use, if the nitrogen and potassium must be purchased in commercial carriers; but in farm manure nitrogen and potassium may be secured practically without cost, and these experiments have shown that such manure may be made as effective a carrier of these elements of fertility as the most active forms in which they are found in commercial fertilizers.

PRACTICAL SUGGESTIONS.

Phosphorus is relatively deficient in most Ohio soils, and may be applied at the rate of 80 to 160 pounds per acre to any crop and on any soil with assurance of a profitable return in the great majority of cases. The usual carriers of phosphorus are acid phosphate and steamed bone meal, and when no other element of fertility than phosphorus is used one of these carriers should be employed. Steamed bone meal costs more per ton than acid phosphate, but it carries more phosphorus, so that the pound of actual phosphorus costs about the same in both carriers.

Phosphorus alone will not produce a maximum yield on lands that have been subjected for a long time to exhaustive cropping. Such lands must have nitrogen always, potassium often, and lime sometimes, before they will yield a full return. Lime is seldom needed over the western half of the state, because the soil in that region has been produced by the grinding up and weathering of limestone rocks and gravels; but in the eastern half it is often deficient. The need of lime may be determined by the growth of clover. So long as clover grows luxuriantly lime is not required, but when clover fails to grow on well manured land, dying out the second season and being replaced by sorrel, then lime should be added. Lime should always be preceded and followed by liberal fertilizing or manuring, for lime used alone, while it may stimulate the land to extra production for a year or two, will in the end produce greater exhaustion; but by alternating lime with manure and fertilizers the land will be kept in a healthy condition and will steadily increase in fertility. This is why limestone soils are celebrated for their productiveness.

Potassium is likely to be needed in soils which have been exhaustively cropped, especially if hay and straw have been sold from the land as well as grain. It is also sometimes the chief element needed on muck soils.

Nitrogen is invariably needed on hard-run lands, but it costs more, if purchased in fertilizers in quantity sufficient to meet the demands of the soil for full crop production, than phosphorus and potassium combined. Note the cost of the different elements in the fertilizer which has produced the greatest effect on the worn soil at the main station—$12.00 for nitrogen, as against $8.90 for phosphorus and potassium combined—yet no smaller ratio of nitrogen in the fertilizer has produced an equal net effect. But this nitrogen may be procured absolutely without cost by growing clover, feeding that to live stock and returning the manure to the land. Such management will also postpone indefinitely the necessity for purchasing potassium, the next most expensive constituent of the fertilizer.

As a temporary expedient the purchase of nitrogen may be justified, as for a crop which must follow clover at a distance of several years; such a crop, for instance, as the wheat crop in the 5-year rotation above described. And the reason, that the wheat crop has shown so much greater effect from the nitrogen in the fertilizers in these experiments than the corn or oats crop, is probably chiefly because these crops, preceding the wheat in the rotation, have consumed most of the surplus nitrogen left by the clover. But when a crop responds to nitrogen as does the wheat crop in this long rotation, this fact of itself is evidence that our system of management is wrong, and that leguminous crops do not appear with sufficient frequency in our rotation.

While clover, therefore, will supply a considerable excess of nitrogen for subsequent crops, it must not be expected that the growing of a crop of clover once in 5 or 6 years will furnish enough nitrogen for all the other crops of the rotation. Clover, or some other leguminous crop, such as the Soy bean, should appear in the rotation not less often than once in three years, and even then, on most Ohio soils, it will be found profitable to supplement the clover with manure; and when this is done with manure that has been treated with the crude phosphate rock of Tennessee, which may be bought in carloads at about $8.00 per ton, delivered to average Ohio points, and which contains as much phosphorus as steamed bone meal, or twice as much as acid phosphate, the conditions will have been fulfiilled for the maintenance and increase of the fertility of the soil by the most effective and economical method that is now known.